Forecasting scenarios of wind power generation for the next 48 hours to assist decision-making in the Australian National Electricity Market

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ABSTRACT

Wind power forecasts can assist decision-making in day-to-day power system operation, and thus facilitate wind power integration. This paper presents the work in progress for the current wind power forecasting project undertaken by the University of New South Wales in collaboration with the Australian Energy Market Operator (AEMO). The aim of the project is to develop a visual decision support tool to forecast large rapid changes in wind power to assist the management of power system security in the Australian National Electricity Market (NEM). The approach is to utilise Numerical Weather Prediction (NWP) data at multiple grid points in the vicinity of each wind farm of interest to produce automated multiple potential scenarios for wind farm generation. Data from the European Centre for Medium-Range Weather Forecasts (ECMWF) NWP global forecast model has been collected along with the observations from 18 wind farms in south-eastern Australia[1]. The methodologies and some resulting forecasts will be discussed and compared with more conventional wind power forecasting methods and presentation formats. The criterion for comparison is how the information could be interpreted by the forecast user and be used to assist decision-making.

Keywords: short-term wind power forecasting

INTRODUCTION AND BACKGROUND ON WIND POWER FORECASTING

Wind power forecasting can greatly assist decision-making by participants in an electricity industry with a high level of wind energy penetration. Wind farm operators can use short (5-minute) wind power forecasts for operational control and multi-day forecasts to prepare maintenance schedules. All generators and end-users participating in electricity markets can use wind power forecasts to improve their bidding strategies since in some electricity industries wind power may have an influence on market prices (Cutler *et al*. 2009a). Power system operators can benefit from information on critical events that threaten system security, such as a potential large rapid change in wind

[1] Source of wind power generation observations: http://www.aemo.com.au/data/csv.html

power generation. In each of the above cases an uncertain large and rapid change in wind power is likely to have significant albeit differing impacts on participant decision-making and its outcomes (from causing undesirable loadings on the wind turbines through to a rapid call for thermal unit start ups).

For all industry participants, the wind power forecasting techniques and presentation formats might best be tailored differently to meet the specific needs of the forecast user. For example, in some circumstances, the most useful forecast would be a single scenario, such as a "best-guess" that statistically has the smallest average forecast error (where the error is defined as the difference in amplitude between the forecast and observed values at each time-step). Commonly used chronology-independent average forecast error scores are the mean absolute error (MAE) and the root mean square error (RMSE) and great progress has been made on optimising wind power forecasts for these scores (Madsen *et al.* 2005, Ernst *et al.* 2008, Sanchez 2005). However, there are wind forecast applications for which chronology of wind power behaviour is important and optimising for error scores such as RMSE or MAE can compromise the chronological veracity of the forecast (Cutler *et al.* 2007, AWS Truewind 2008). An example of this is a tendency for the "best guess" forecast to hedge towards the climatological mean during periods of large, uncertain rapid changes to avoid increasing the average forecast error score. This paper discusses a forecasting approach that aims to provide useful chronological information for a single wind farm or a group of wind farms with a particular focus on large rapid changes in wind power. This is being developed in a UNSW research project, in conjunction with the Australian Electricity Market Operator (AEMO).

The paper is structured around three main sections followed by some concluding remarks. The first of the main sections provides some background for the wind power forecasting techniques being developed in the project and shows some examples of the results for the National Electricity Market. The second section provides more specific details for the project. The third section discusses various practical issues with wind power forecasting for managing power system security applications, including some specific issues for the Australian National Electricity Market and AEMO.

TECHNIQUES FOR FORECASTING LARGE RAPID CHANGES IN WIND POWER

As introduced above, this paper discusses a forecasting approach that aims to provide useful chronological information for a single wind farm or a group of wind farms. The most critical events of interest are when the chronological change in wind power is potentially highly significant, or in other words, when a large rapid change in wind power might occur. Large rapid changes in the power output of a single wind farm or a group of wind farms may not be well predicted using statistical techniques based on past on-site observations because there is unlikely to be any warning signal with a significant lead-time in on-site observations. Appropriately placed off-site observations can help predict large rapid changes for 1-2 hours ahead under specific conditions (Larson and Westrick 2007).

However, the most generally applicable tool to predict large rapid changes is a Numerical Weather Prediction (NWP) system. These mathematically based computer models of the atmosphere have been developed by weather forecast organisations around the world and are used routinely for a range of weather forecasting applications. They model the atmospheric region of interest with a three dimensional grid and undertake two main procedures to produce a forecast; first they estimate an initial state of the atmosphere at each grid point and second, they solve equations representing the laws of atmospheric behaviour in response to exogenous drivers and disturbances to forecast how the initial state of the atmosphere might evolve in time. NWP systems are used to generate forecasts of atmospheric behaviour over forecast horizons of 48 hours or more. A relevant example is the European Centre for Medium Range Weather Forecasts (ECMWF) which has an NWP system that models the global atmosphere at a horizontal grid resolution of 16 km over a forecast horizon of several days (ECMWF 2010).

Recent research (Cutler *et al.* 2009b, Lange and Focken 2006) has highlighted some important traits of NWP systems for wind power forecasting. They have good skill in forecasting synoptic weather systems and how these influence near-surface wind features, but they may misplace these wind features relative to the earth's surface (Cutler *et al.* 2009b). This 'misplacement error' can be vertical or horizontal within the three-dimension model of the atmosphere, but for the Australian wind farms that we have studied misplacements of significance were found to be predominantly in the horizontal dimension. It is important to note that NWP models cannot resolve the fine scale near surface wind features below their grid resolution, such as turbulence and other topographical induced eddies. However these will generally cause only relatively small wind speed forecast errors and are unlikely to be the cause of large rapid changes in wind power except in the case of wind gusts that exceed the design shut-down wind speed of a group of wind turbines.

Single wind power forecast scenarios are usually derived from a single NWP forecast by compiling the wind forecasts from each NWP time-step over the forecast horizon at a single grid point (or interpolation of grid points) that represents the location of a wind farm of interest. Those wind forecasts are then transformed to wind power forecasts by using a previously estimated wind power curve for the wind farm. Because of uncertainty in forecasting rapid changes in wind power as highlighted above, forecast users might greatly benefit from multiple scenario forecasting techniques since it allows them to prepare for a set of potentially quite different yet plausible scenarios for wind farm power output. It is thus important that these multiple scenarios are each chronologically consistent with the underlying behaviour predicted by the NWP system.

Multiple wind power forecast scenarios are commonly produced using an ensemble of NWP forecasts that accounts for at least some uncertainty in the NWP modelling process. The NWP ensemble members may be based on slightly different initial conditions, or use different physical assumptions about atmospheric behaviour. Single forecast scenarios are extracted from each NWP ensemble method using the single grid point method described above to compile multiple forecast scenarios. However, NWP ensembles are more computationally expensive than single NWP forecasts at the same spatial resolution. Consequently, spatial resolution is usually compromised in NWP ensemble forecasting (eg 32 km instead of 16 km in the ECMWF case) and weather forecast organisations may set a higher price for them. The next section presents a different method to produce multiple scenarios utilising data from multiple grid points in a single NWP forecast.

The multiple grid point method

As described above, the conventional method for using forecast information from an NWP output data set is to extract the data at a single NWP grid point for each time step. Due to possible misplacement error, this method may miss useful information at nearby grid points in the NWP data set at a particular simulation time step. Additionally, the single grid point forecast may miss further information due to temporal aliasing, since the NWP data set is only available at particular simulation time steps, such as hourly.

Utilising data at multiple NWP grid points at each simulation time step may provide more information on the possible future behaviour of wind farm power output. However the wind speed forecasts at each grid point are influenced by the way terrain local to that grid point is modelled in the NWP system. For example, wind speeds near the earth's surface over the ocean tend to be stronger than over land because the surface of the land is rougher than the ocean. Surface roughness effects are represented in the NWP model, so that if a given weather feature is over the ocean, higher near-surface wind speeds will be predicted than if the same weather feature was over the land. Hence, we have developed a 'terrain standardisation' method to establish relationships between predicted wind speeds at neighbouring grid points. This method uses a NWP data set that covers a long period of time (one year or more) to establish these relationships (Cutler *et al.* 2009b). The result is a horizontal grid of standardised wind speeds, where the wind farm of interest (or cluster of wind farms in close proximity) is located in the middle. A graphical example of the raw wind speeds and the standardised wind speeds is shown in **Figure 1** for a wind farm on the south coast of Australia, using a particular forecast from the ECMWF global model with a projection time of 15 hours ahead.

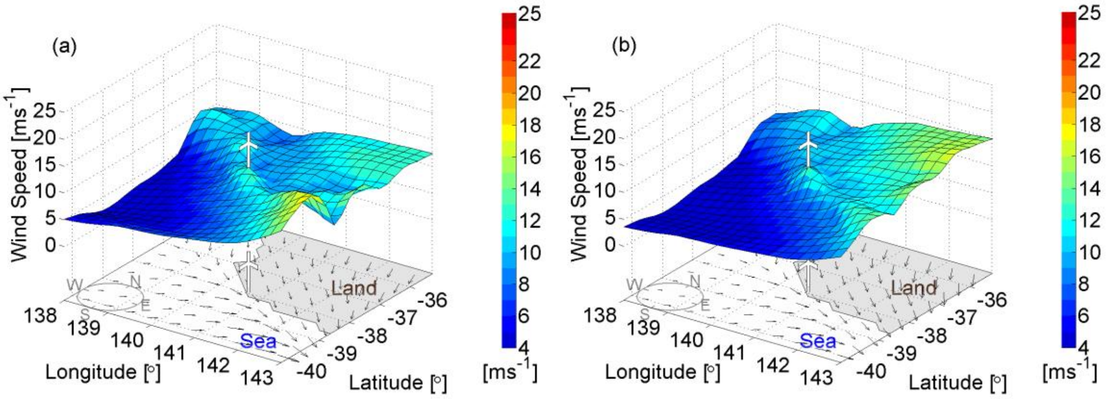

Figure 1: (a) raw and (b) standardised wind speed fields for an ECMWF forecast with projection time 15 hours ahead. Each plot (a) and (b) shows the wind speed fields in a 3D plot with the wind direction field shown on a 2D plot beneath it. The wind turbine symbol indicates the modelled location of the wind farm. Note how the standardised field has generally lower wind speeds over the ocean and higher over land compared with the raw field.

The standardised wind speed field can then be transformed to wind power (based on a wind power curve developed using past single grid point wind speed forecasts and wind power observations) to produce a 'site-equivalent wind power forecast field'. The wind power values are site-equivalent because of the terrain standardisation, meaning that all wind power values in the field are directly applicable to the targeted wind farm. Successive wind power forecast fields can be used to estimate the speed and direction of propagation of wind features (the algorithm for this will be published in a future paper). For the same example as in **Figure 1**, the wind power forecast field is shown in **Figure 2**, with several wind turbine symbols to indicate alternative scenario forecasts illustrating potential misplacement errors.

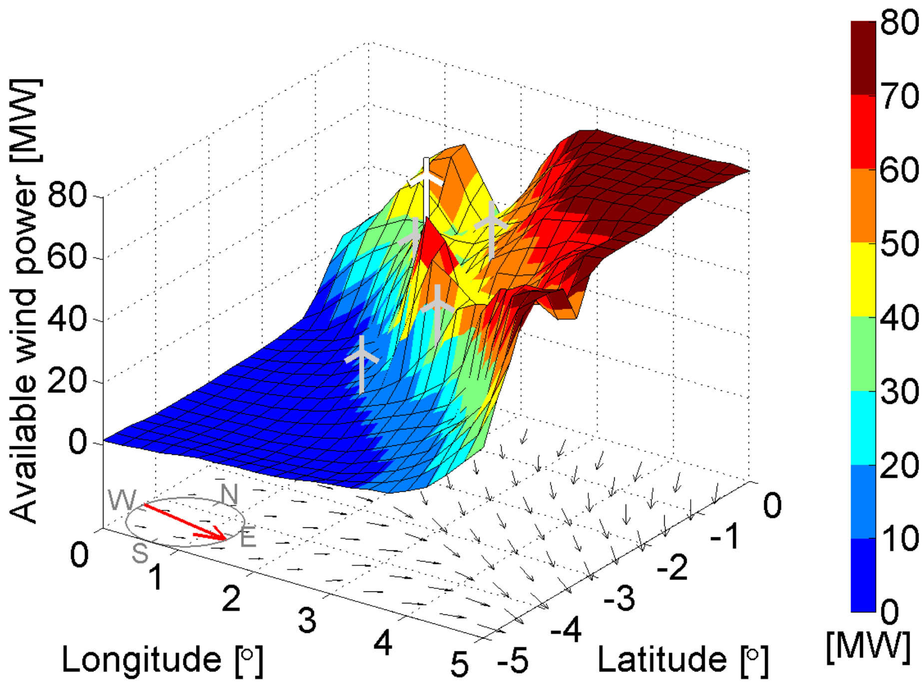

Figure 2: The wind power forecast field for the same example as in Figure 1. The modelled wind farm location is again shown with the white, outlined wind turbine symbol, and four other possible wind farm locations are shown that represent four illustrative misplacement errors. The estimated propagation direction for the wind features is indicated by red arrow on the compass, where the arrow length indicates the speed of propagation of the wind feature. The longitude and latitude values have been made generic to help clarify the misplacement concept where there are many possible positions of this wind power field relative to the surface of the earth

Displaying the site-equivalent wind power forecast field, such as in **Figure 2**, provides a visual tool to characterise uncertainty in the NWP system forecast. In this example, the white, uppermost wind turbine symbol, representing the actual location of a wind farm, is situated at a point of high wind power relative to the surrounding wind power field. The four grey wind turbine symbols on the wind power field represent possible misplacement errors of the wind feature forecast by the NWP with respect to the wind farm. They highlight that even a small misplacement error in any direction would result in a lower wind farm power at the particular time for which the forecast was issued. Thus we may infer that the predicted wind power value at the actual location of the wind farm has a low probability of being correct at the issued time.

Using the wind power field, a forecast user can also predict potential chronological changes in wind power by using the estimated speed and direction of propagation of the dominant wind power feature (shown by the red arrow in the compass). In **Figure 2**, the white wind turbine and each of the four grey misplaced turbines suggest five different scenarios for how the wind power may change. Furthermore, an animation of successive wind power fields for each time-step in the NWP data provides a visualisation of the propagation of wind power field features through a longer period of time. By contrast, a single grid point forecast may suffer from aliasing, or sampling error, such as if it falls on a sharp peak in the spatial wind power forecast (as in the example shown in **Figure 2**). This example highlights how a single grid point forecast can miss useful information because it provides only the predicted wind power value at the assumed wind farm location relative to the wind power field for each time step.

Figure 3 shows a single grid point forecast derived from twelve consecutive wind power fields at three-hour intervals (including the wind power field in Figure 2) along with some other potential scenarios that take into account possible misplacement errors. The corresponding half-hourly observations of wind power generation from the wind farm are also shown for comparison. At a projection time of 15 hours (corresponding with the wind power field in Figure 2), the single grid point prediction is above 70 MW and subsequently drops rapidly to around 10 MW in three hours. However the misplacement error scenarios indicate with a high level certainty that a rapid drop in wind power will occur, but that it may occur up to three hours earlier. The observations show that the wind power does indeed start to drop around three hours earlier than predicted by the single grid point forecast and then increases a little before dropping to less than 10 MW. In this example, the single grid point forecast was reasonably good for most of the 36-hour period, but had a large error at a projection time of about 15 hours. The wind power forecast fields provide additional insights about how the event might evolve, by highlighting the nature of the uncertainty around the projection time of 15 hours.

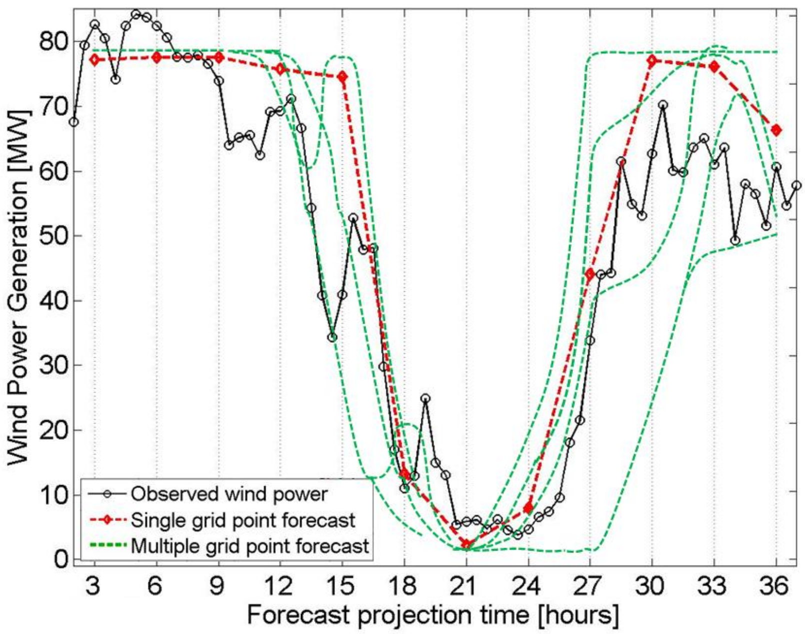

Figure 3: A time-series plot of the single grid point forecast and multiple scenarios from the ECMWF NWP system along with the actual half-hourly wind farm power observations

WIND POWER FORECASTING AT AEMO AND THIS SPECIFIC PROJECT

The Australian Energy Market Operator (AEMO) is funding and participating in this project, which is to develop a prototype tool for forecasting large rapid changes in wind power. If successful, this project might provide an enhancement to the Australian Wind Energy Forecasting System (AWEFS) project in which AEMO installed a commercial wind power forecasting system (AEMO 2010). The project was financed by the Commonwealth Department of Resources, Energy and Tourism (DRET) and is due to be completed in 2010. The successful supplier was the European consortium, ANEMOS[2]. These recent developments in wind power forecasting in Australia largely result from government planning for the rapid expansion of Australia's wind farm installations over the recent decade, particularly in the South Australian region of the

[2] Development of **A NE**xt Generation Wind Resource Forecasting Syste**M** for the Large-Scale Integration of **O**nshore and Off**S**hore Wind Farms. http://anemos.cma.fr/

Australian National Electricity Market. Australia currently has more than 1600 MW of wind power capacity installed, and more than half of this (868 MW) is installed in South Australia. Other recent studies on wind generation in South Australia include (Cutler *et al.* 2009, ESIPC 2009, Weston 2009).

In the current project, the prototype forecasting tool will undergo a user acceptance testing procedure in which AEMO personnel will assess its merit for possible further development into an operational tool as part of the AWEFS system in the power system control room. A set of critical large rapid change event categories have been identified on which to test the prototype tool. These are as follows:

Event category 1: Total wind generation in South Australia changes by more than a pre-specified amount in 30 minutes.

Event category 2: The summated wind generation from the south-east region of South Australia changes by more than a pre-specified amount in 30 minutes. The south-east region currently comprises of three wind farms: Canunda, Lake Bonney 1 and Lake Bonney 2 with a total installed capacity of 286 MW.

Event category 3: The total wind generation in Tasmania changes by more than a pre-specified amount in 30 minutes.

For each of these event categories, the prototype tool is to provide the following outputs:

- Raising alarms when there is the possibility of an event category occurring according to the most recently available NWP forecast,
- For each of the raised alarms, a presentation of the available forecast information is to be provided highlighting plausible multiple scenarios for wind power generation. This information will be provided in two forms (where both forms have been described in detail in the previous section):
    - An animation of successive wind power spatial fields,
    - A time-series plot showing the multiple scenarios, possibly with an indication of their associated probability.

The user acceptance test criteria will include an element of judgement assuming that the power system operator would prefer information that they can quickly assimilate to make a more informed decision. In addition to this, some evaluation scores have been defined as follows. These will be estimated for each event category.

- Number of alarms produced. This should be minimised so that the power system operators are not responding to too many alarms.
- Number of events that actually occur and were not alarmed, or ‘missed’ events. This should also be minimised.
- Number of events where the predicted timing of the event was within 60 minutes of the actual timing of the event. This should be maximised, since it is undesirable that a multiple scenario forecast would not contain at least one scenario where the event occurs within 60 minutes of the actual event.
- Average number of forecast scenarios provided for each alarmed event. This should be minimised to encourage that the uncertainty is reduced where possible, making the forecast information more useful.

PRACTICAL ISSUES FOR FORECASTING WIND POWER TO MANAGE POWER SYSTEM SECURITY

There are various unresolved issues regarding the implementation and operational use of wind power forecasts for the management of power system security. Some of the more important of these are as follows:

- **Input data quality.** As with any system, wind power forecasts are reliant on the quality of the input data to the forecasting system. This refers to the quality and reliability of the NWP system used as well as the historical observations at wind farms including wind power generation and wind turbine availability. High quality forecasts of wind turbine availability are also crucial to the accuracy of predictions of wind farm power output. Furthermore, NWP systems often only provide wind forecast data near turbine hub height with a temporal resolution of 3 hours whereas more frequent NWP data at hub height would be preferable, such as hourly. This is particularly important for operation forecasts in real time.
- **Decision-making procedure development.** Since wind power forecasts are a relatively new set of information for power system control rooms, additional decision-making procedures may be required to facilitate the most appropriate decisions being made, taking into account the state of the power system at the time.
- **Integrating wind power forecasts into the control room routine tasks.** Power system operators already manage a large number of tasks including assessing large quantities of time-varying information. Thus, they require wind power forecast presentation formats that allow them to quickly assess the situation and make informed decisions. Fortunately, NWP forecasts are provided for forecast horizons of 48 hours or more and a new NWP forecast is typically produced every 6 or 12 hours. This means that power system operators are likely to receive wind power predictions at least several hours and up to a day or two ahead. While time-series presentation of predicted behaviour may be more familiar, spatial field presentation can potentially take advantage of humans' superior pattern recognition skills and direct the eye to the more extreme scenarios of potential large rapid changes in wind power, which are the most important scenarios for managing power system security.

CONCLUSIONS AND FURTHER WORK

A wind power forecast system may be usefully designed to meet the intended user's specific needs beyond conventional forecasting methods and presentation techniques. Researchers in the field are still learning which wind power forecasting techniques and presentation methods might best meet the needs of forecast users. In this paper we have demonstrated a method that utilises data from multiple grid points in an NWP model to provide useful information on potential scenarios for wind power generation. The method shows promise for characterising large rapid changes in wind power and has been evaluated for some wind farm sites in Australia. The paper also describes a current application, in which we are developing a prototype tool for predicting large rapid changes in wind power for the Australian Energy Market Operator. Specific large rapid change event categories will be used to evaluate the prototype model. Progress to date is promising.

Potential future work includes investigating the development of a forecast tool for commercial decision-makers in the Australian NEM. Other research (Cutler *et al.* 2009a) suggests an emerging relationship between wind power and electricity prices in South Australia, including more common incidences of low or even negative prices at times of high wind generation, and typically higher spot prices at times of low wind generation.

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BRIEF BIOGRAPHY OF PRESENTER

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